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Exploring the competitive evolution of global wood forest product trade based on complex network analysis

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HIGHLIGHTS

- The paper considered the competitive relationship of global wood forest product trade.
- TThe paper constructed global unweighted and weighted wood-forest-product competitive network, and studied spatial competitive evolution of global wood forest product trade.
- The U.S. played an important role in the global competition system, but China and other Asian countries gradually became the center of global wood-forest-product competition.

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ABSTRACT

Due to globally uneven distribution of forest resources and timely difference of supply and demand, forest products are difficult to achieve market equilibrium among neighboring countries. The global forest product trade not only alleviates the contradiction of supply and demand, but also ensures the sustainable development of the economic construction for each country. Previous literature analyzed the structure and evolution mechanism of forest product trade from different perspectives, but ignored the competitive relationships among forest product importers. Based on complex network theory, this paper selected global wood forest product trade data from 2004 to 2016. Then we constructed global unweighted and weighted wood-forest-product competitive network from import perspective, and three indicators (density, average path length, and clustering coefficient), core–periphery model and two indicators of competitive intensity were introduced to study the spatial competitive evolution of global wood forest product trade among countries. The results showed that there was wide competition in global wood forest product trade among continents, and the tightness of competitive relationships gradually decreased with time. Secondly, core countries and periphery countries were clearly identified in the competitive network, and China, Japan, the U.S., were the main core countries influencing the evolution of core–periphery structure. Finally, the U.S. played an important role in the global competition system. But with the increment of demand for Asian market, China and other Asian countries gradually became the center of wood-forest-product competition. The research tried to provide some references for importers to follow the laws of global wood forest product trade, and formulate the corresponding policy under constructing sustainable society and facing climate change.

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1. Introduction

Forest resources play significant roles in the development of economic [1], while global forest resources are decreasing. According to "Global Forest Resource Assessment 2015" [2], global forest area has decreased from 4.13 billion hectares in 1990 to 3.99 billion hectares in 2015. Besides, due to the uneven distribution of forest resources, more than 50% of forest resources are only concentrated on several countries, causing the forest product trade to become a significant way to meet domestic forest product demand for many forest-product-consuming countries. Therefore, many scholars studied global and regional forest-product trade, and attempted to examine influential factors, sustainable forest resources management and so on [3–8].

However, with global rapid economic development and domestic forest resource protection, more and more countries, even some traditional exporters, import a large number of forest products [9]. Thus, serious contradiction between supply and demand, created by increasing numbers of forest product importers, may inevitably strengthen the competition for forest resources. Some works focused on the impact of some factors on forest-product-trading competition. Zhang [10] selected global forest-product trade data and studied the competition of forest-product trade based on Helpman–Krugman theory. The results illustrated that the monopolistic competition widely existed in global forest-product trade. Dieter [11] analyzed the competitiveness of the German forest industry sector against the background of global timber market using competitiveness indicators. The results found that most leading timber exporters in absolute terms showed low export growth rates and Germany's export growth can be attributed much more to the overall world growth in timber markets than to its forest industry capacity. Paluš [12] collected the data of Slovak wood trade from 2003 to 2012, and analyzed the competitiveness of the Slovak wood processing industry sectors and their comparison with the Visegrad group countries. The paper found that Slovakia had revealed comparative advantage in most of the products, and intra-industry specialization was increasing with the level of value added to products. Miao [13] selected forest-product trade data and studied the complementarity and competitiveness of forest products trade between China and B&D (Belt and Road) countries. The results showed there was lack of global competitiveness for these countries' trade, and China should strengthen global cooperation and improve the globalization level of forestry industry.

Previous researches mainly focused on forest-product trade and studied the structural characteristics of global and regional trade. However, as fierce contradiction between supply and demand of global forest resources, the competition among global forest-product trade is gradually prominent. Meanwhile, the research on competition of global forest-product trade was ignored, and few researches studied the spatial competitive characteristics of global forest-product trade. In this paper, we mainly focused on wood forest product from import perspective, and constructed global wood-forest-product-trading network using complex network that has been applied in different fields [14–16]. Then, we analyzed the spatial competitive evolution of global wood forest product trade. The paper attempted to provide some references for importers to follow the laws of global wood forest product trade and formulate the corresponding policy under constructing sustainable society and facing climate change.

The main contributions of this paper are as follows. Firstly, we constructed wood-forest-product competitive network, and investigated the structural characteristics and evolutionary laws of wood-forest-product competitive network, which has been ignored by previous literature. Secondly, considering the difference of network links, we introduced a new indicator (competitive intensity), and took it as network link weigh. Finally, we constructed the weighted wood-forest-product competitive network, and studied the main competitive regions, the large forest-product-consuming countries' positions, the transmission of competitive relationships and the spatial evolution of competitive relationships among wood-forest-product countries.

The rest of the paper is organized as follows. Section 2 introduced modeling process and data source. Then, the empirical analysis and results of wood-forest-product competitive network were discussed in Section 3. We concluded the paper and further research directions in Section 4.

2. Model and data

Due to the concentration of forest resources, there may be more than one country inevitably import forest products from the same forest-product exporter. Besides, some traditional forest-product exporters, such as Germany, have become net forest-product importers due to protecting forest resources. Thus, the serious contradiction between supply and demand, created by increasingly concentrated forest-product-producing regions and increasing numbers of forest-product importers, will inevitably intensify the competition for forest-product. This paper focused on global wood-forest-product-trading competition and explored the spatial competitive characteristics of global wood forest product trade.

2.1. Wood-forest-product competitive network (WFPCN)

Global wood-forest-product competitive relationships can be taken as a network, and described by the set G= (V, E), where wood-forest-product importers V= $(v_1, v_2, \ldots, v_n)$ are denoted as network nodes, and competitive relationships E=$\{e_{ij}\}$ are represented as network links. If there is the same import source for wood-forest-product importers v_i and v_j, $e_{ij} = 1$. Otherwise, $e_{ij} = 0$.

2.1.1. The topological structure of WFPCN

Based on the competitive network, three indicators are introduced to analyze the topological structure of WFPCN: density, average path length, and clustering coefficient.

(1) Density

The density is applied to measure the tightness among all of the countries in the WFPCN. The definition of density indicator is given by [17]:

$$\varphi = \frac{2m}{n(n-1)}, \tag{1}$$

where m represents the number of competitive relationships, and n denotes the number of countries in the competitive network

(2) Average path length

The average path length is defined as the average number of steps along the shortest paths for all possible pairs of competitive network nodes in the WFPCN. Thus, the average path length is represented as follows [18]:

$$L = \frac{1}{n(n-1)} \sum_{i,j} d_{ij}, \tag{2}$$

where n denotes the number of countries, and d_{ij} denotes the shortest distance between countries v_i and v_j. If country v_i and v_j cannot reach each other or $v_i = v_j$, it is assumed that $d_{ij} = 0$.

(3) Clustering coefficient

The clustering coefficient is introduced to evaluate the tightness between two countries that connected with the same country in the network. A large value of clustering coefficient indicates that the neighbors of the country compete with each other fiercely. The clustering coefficient (c_i) is defined as follows [18]:

$$c_i = \frac{2a_i}{k_i(k_i-1)}, \tag{3}$$

where k_i is the number of countries that v_i connects with, and a_i denotes the number of links among the neighbors of country v_i. The network average clustering coefficient $\overline{C}$ is defined as:

$$\overline{C} = \frac{1}{n} \sum_{i=1}^{n} c_i, \tag{4}$$

2.1.2. Core–periphery model

Because of various import source and import volume, the nodes in the network might play a significant role in spatial formation of competitive pattern. The core–periphery model, which has been widely applied in the existing literature [19,20], is used to detect densely-connected "core" and sparsely-connected "periphery" portions of WFPCN in the study. The main idea of core–periphery model is to examine the fitness of core–periphery between the real network structure and the ideal network structure, which can be found through the unnormalized Pearson correlation coefficient (i.e. ρ in Eq. (5)). If $\rho = 1$, the real network structure is the ideal network structure (ideal core–periphery structure), which contains two groups, i.e. the core group in which nodes connect with each other and the periphery group in which nodes disconnected with each other.

Since it is hard to accurately estimate the density of core-to-periphery and periphery-to-core ties, this paper applied the core–periphery detection model recommended by Borgatti and Everett [21], which take the ties as missing value. The indicator (ρ) was given as follows:

$$\begin{gathered} \rho = \textstyle\sum_{i,j} e_{ij}\delta_{ij}, \\ \delta_{ij} = \begin{cases} 1 & \text{if } g_i = \text{CORE and } g_j = \text{CORE}, \\ 0 & \text{if } g_i = \text{PERIPHERY and } g_j = \text{PERIPHERY}, \\ \bullet & \text{otherwise}, \end{cases} \end{gathered} \tag{5}$$

where ρ indicates the unnormalized Pearson correlation coefficient, and ρ ($\rho \in [0,1]$) represents the fitness of core–periphery between the real network structure and the ideal network structure. e_{ij} is the link between countries v_i and v_j, g_i (g_j) is the group (core or periphery) that country v_i (v_j) is assigned to, δ_{ij} represents the absence or the presence of a tie in the ideal core–periphery structure and "•" indicates the missing value.

2.2. Weighted wood-forest-product competitive network (WWFPCN)

The WFPCN being constructed in Section 2.1 considered the competitive relationships among importers. However, due to various import volume, the intensity level of competition among importers might be different. Thus, we applied the indicator proposed by Glick and Rose [22] to measure the competitive intensity. The competitive intensity was taken as

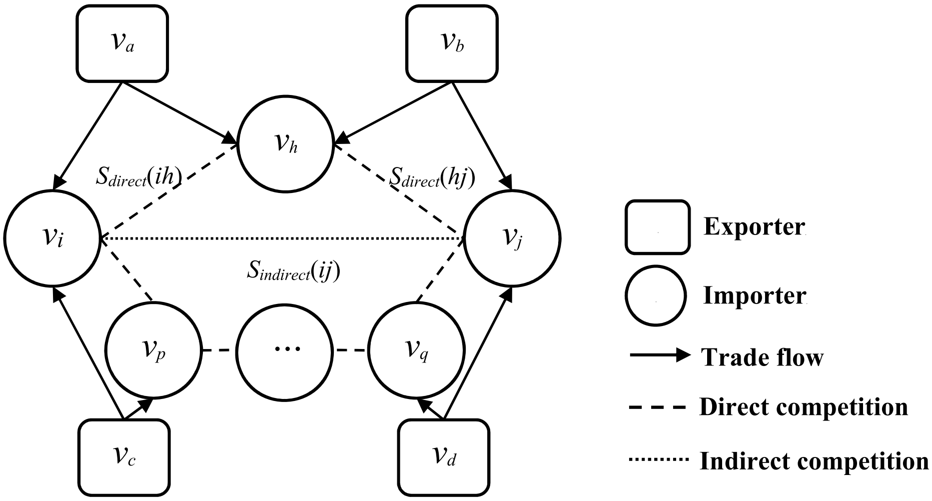

Fig. 1. Overview of competitive relationships.

the link weight, and the WWFPCN was constructed to examine the evolution of wood-forest-product-trading competition. The research on the structure of WWFPCN would uncover more complex laws of global wood-forest-product competition.

The paper mainly considered two indicators of competitive intensity: direct and indirect competitive intensity. The indicator of direct competitive intensity ($S_{direct}(ij)$) is defined as follows:

$$S_{direct}(ij) = \sum_k \left\{ \left(\frac{Y_{ki} + Y_{kj}}{Y_t} \right) \times \left[1 - \frac{\left| (Y_{ki}/Y_i) - (Y_{kj}/Y_j) \right|}{(Y_{ki}/Y_i) + (Y_{kj}/Y_j)} \right] \right\} \times 100, \tag{6}$$

where k indicates the country that exports wood forest product to countries v_i and v_j, Y_{ki} (Y_{kj}) indicates the total volume that country v_i (v_j) import wood forest product from country v_k, Y_t represents global total import volume and Y_i (Y_j) indicates gross import volume for country v_i (v_j).

Besides, two wood-forest-product importers without direct competition could have an indirect competitive relationship through their common neighboring countries. The path v_i- v_h - v_j, shown in Fig. 1, was taken as an example to illustrate the indirect competitive relationships between importers v_i and v_j. In Fig. 1, the countries v_h, v_i, v_j, v_p and v_q in the circles import wood-forest-product from the countries v_a, v_b, v_c and v_d in the boxes. The solid line with arrow represents the trade flow, the dashed line indicates the direct competition, and dotted line describes the indirect competition. Obviously, there is no direct competitive relationship between importers v_i and v_j, but the change of direct competitive relationships (v_i, v_h) and (v_h, v_j) might influence the indirect competition between v_i and v_j. The importer v_i will indirectly compete with v_j through their common competitor v_h. There might be many long transmission paths, like v_i- v_p - $\cdots$- v_q - v_j, to transmit the indirect competition through mediators (for example v_p, v_q and so on). But various uncertain events may lead to the reduce or disappearance of indirect competition in the long competitive chain. Thus, this paper focused on the indirect competition passing through one mediator (for example the indirect competition between v_i and v_j in the path v_i- v_h - v_j of Fig. 1). The indicator of indirect competitive intensity ($S_{indirect}(ij)$) is as follows:

$$S_{indirect}(ij) = \sum_h^{\Delta} \frac{1}{1/S_{direct}(ih) + 1/S_{direct}(hj)}, \tag{7}$$

where h denotes the mediator v_h on the transmission path (v_i– v_h - v_j in Fig. 1), and Δ represents the set of mediators.

2.3. Data source

The paper obtained wood forest product trade data from the *United Nations Commodity Trade Statistics Database* (UNCOMTRADE) [23]. In the study, we considered wood-forest-product-trading competition from 2004 to 2016 to examine the spatial evolution of competitive network. There is specific HS code for each commodity, and the wood forest product code of the paper is 44 (including wood and articles of wood) following previous reference [23].

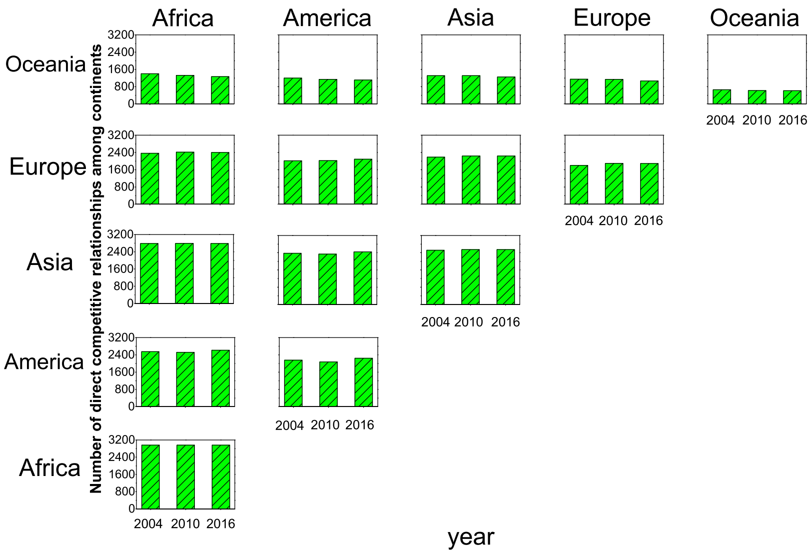

Fig. 2. The competition among five continents in 2004, 2010 and 2016.

3. Results

3.1. The analysis of WFPCN

With the development of economy [24–26], plenty of countries import wood forest products from the countries with rich forest resources, which contributes to global competitive relationships around the world. In order to describe spatial competitive evolution by regions, we studied the competitive relationships among five continents with time (Fig. 2). Each bar in Fig. 2 represents the number of direct competitive links between two continents for each year, and high bar means fierce competition between two continents. It is found that there is wide competition in the global wood forest product trade among continents. Specifically, Africa and Asia face high competitive pressure, of which intra-African and intra-Asian competition are the major source of pressure due to their relatively stable demand and import sources for economic development. However, considering competitive evolution among continents, the situation is becoming complex. Some competitive relationships between two continents become weaker, and some become stronger. Meanwhile, the tightness of competitive relationships is gradually fierce with time, which can be found from the competitive evolution between Europe and other continents with time (the number of links between Europe and Africa, America, Asia, Europe are from 2361 in 2004 to 2398 in 2016, 2015 in 2004 to 2091 in 2016, 2188 in 2004 to 2237 in 2016, and 1804 in 2004 to 1888 in 2016, respectively).

In order to depict the tightness of global competition and the evolution over time, the paper studied three indicators of WFPCN: density, average path length and average clustering coefficient. It is illustrated in Fig. 3 that the value of average clustering coefficient is 0.98 (the maximum value is 1), which shows the characteristic of competition globalization. Besides, the value of average clustering coefficient in WFPCN slightly decreases with year, reflecting that the number of direct competitive links among importers is decreasing, and the tightness of competition has decreased, which also corresponds to temporal evolution of density and average path length. The value of density is 0.97 (the maximum values is 1) and its value decreases with time. The value of average path length is 1.02 (the minimum value is 1) and its value is increases with time. Such evolution of two indicators also verify previous conclusion of global competitive evolution.

Meanwhile, average clustering coefficient and average path length are also the indicators to judge whether WFPCN is a "small-world" network, which can examine the global competition of wood-forest-product trade. Thus, we applied "small-world-quotient (SWQ)" proposed [27] by to detect WFPCN. In this paper, $SWQ = [\overline{C}/L] \times [\overline{C}_{random}/L_{random}]$, where $\overline{C}$ and L are the average clustering coefficient and average path length of WFPCN, and $\overline{C}_{random}$ and L_{random} are the average clustering coefficient and average path length of the hypothetical random network with the same number of nodes and average degree. If SWO is greater than one, there is the feature of "small world" for the special network. The results are all greater than one (SWQ are respectively 1.0063, 1.0085 and 1.01 in 2004, 2010 and 2016), reflecting that WFPCN has the feature of "small world" network, indicating that any two importers have competitive relationship and the pressure of competition faced by importers is fierce.

To grasp the main competitive countries that influence the evolution of WFPCN, this paper applied software UCINET to differentiate core countries and periphery countries. Fig. 4 shows the evolution of core–periphery structure of WFPCN, where red represents core importers, and pink represents periphery importers. It is found that core countries are mainly

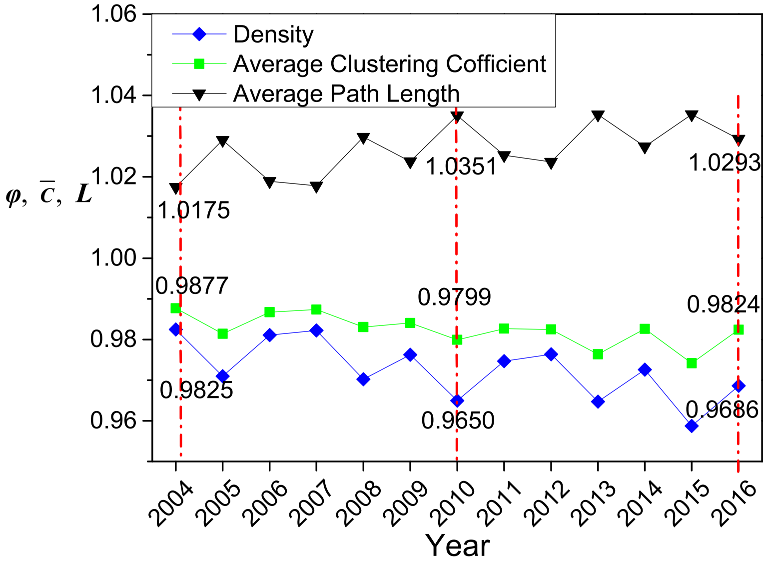

Fig. 3. The dynamic of density (φ), average clustering coefficient ($\overline{C}$) and average path length (L) of WFPCN.

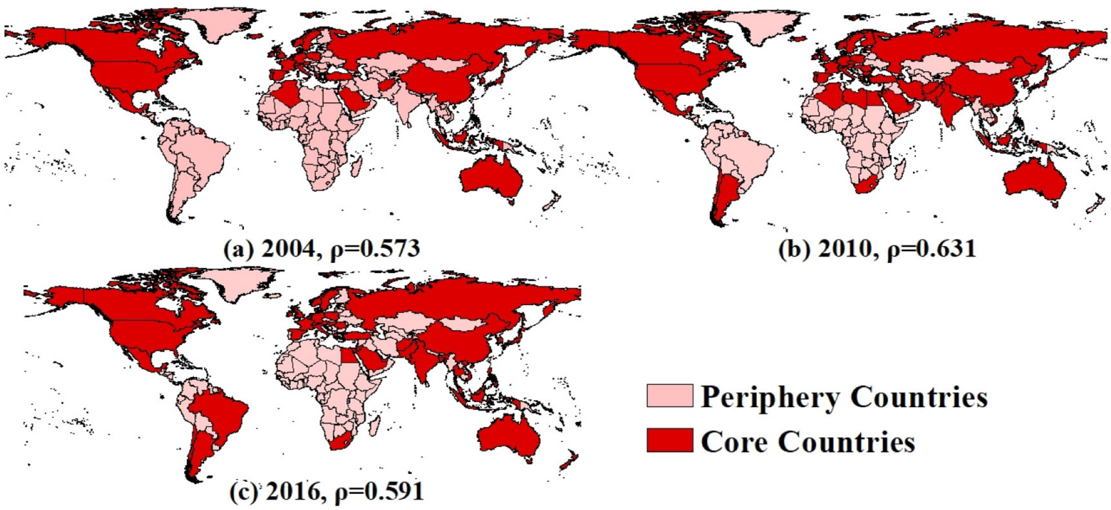

Fig. 4. The evolution of core–periphery structure in WFPCN.

distributed in North America, Europe and Asia with large wood-forest-product demand. Meanwhile, the value of ρ changes over time, and core–periphery structure of WFPCN becomes clear from overall perspective, but there are different changes in different time. From 2004 to 2010, the value of ρ changes from 0.573 to 0.631, illustrating that core–periphery structure becomes clear and resulting from the concentration of import source for importers. However, by 2016, with the development of competition globalization, the competitive relationships among wood-forest-product importers become increasingly complex, and the value of ρ changes from 0.631 to 0.591, which shows that core–periphery structure become vague. Such situation is relative to global strategic changes of wood-forest-product importers. Although the changes of core–periphery structure, some countries, like China, Japan, the U.S., are main importers and core countries, which influence the evolution of WFPCN.

3.2. The analysis of WWFPCN

Since there are various import volume and source for different importers, the competitive intensity of links in the network would be different. Thus, we considered the competitive intensity, and constructed a WWFPCN to study the evolution of wood-forest-product-trading competition. Firstly, we checked the fierce direct competitive relationships in the WWFPCN and examined their evolution. As showed in Table 1, the fiercest competitive relationships in 2004 and 2010

Table 1
The fiercest competitive relationships over time.

Rank	2004	2010	2016
1	Japan-The U.S.	Japan-The U.S.	China-Japan
2	Germany-The U.S.	Japan-South Korea	China-South Korea
3	South Korea-The U.S.	Japan-China	Japan-The U.S.
4	France-The U.S.	Germany-Italy	Japan- South Korea
5	Panama-The U.S.	France-Germany	South Korea-The U.S.
6	Philippines-The U.S.	France-Netherland	China-UK
7	New Zealand-The U.S.	Japan-Saudi Arabia	China- Hong Kong
8	Christmas Island-The U.S.	Japan-Australia	China-Indonesia
9	North Korea-Panama	Panama-The U.S.	China-India
10	Japan- South Korea	South Korea-The U.S.	China-Turkey

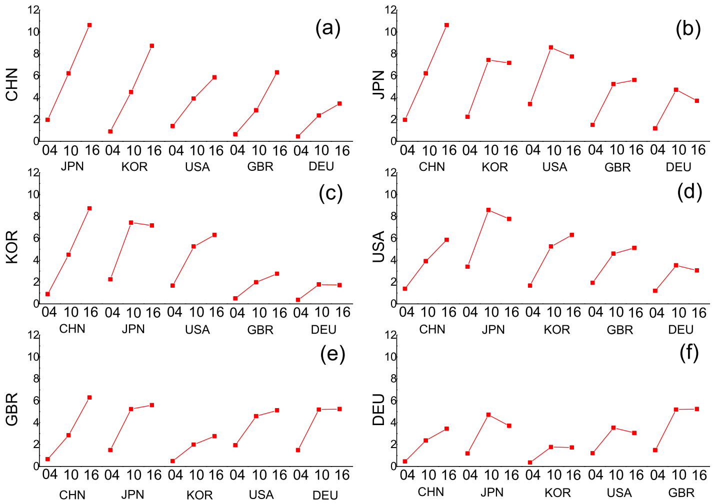

Fig. 5. The dynamic of competitive intensity among six large wood-forest-product importers.

are the same (Japan–the U.S.), but by 2016, China–Japan becomes the fiercest competitive relationships, reflecting that large importers, like Japan, the U.S. and China, are the main countries to influence the evolution of WWFPCN. Besides, the U.S. leads the direct competitive relationships of WWFPCN in 2004, but such situation changes with time. By 2016, due to large import volume, China and other Asian countries gradually become the center of wood-forest-product-trading competition.

Previous conclusion found that large importers played significant role in the evolution of WWFPCN. To further explore the evolution of competitive intensity, we selected six main wood-forest-product importers (including China (CHN), Japan (JPN), South Korea (KOR), the United State (The U.S., or USA), United Kingdom of Great Britain and Northern Ireland (GBR) and Germany (DEU)), and their evolution of direct competitive relationships were described in Fig. 5. It is found that the direct competitive intensity between China and other countries increases over time, but the direct competitive intensity among other countries shows different situation (inverted "U" shape). The direct competitive intensity increases from 2004 to 2010, while the intensity decreases from 2010 to 2016, which is the result of adjustment of import strategy. According to the trend of evolution, China and other Asian countries will gradually become the center of global wood-forest-product consumption and competition in the future.

The indirect competition might influence the evolution of WWFPCN, and such competition is closely related to the "mediator". Therefore, we further studied the main mediators in the WWFPCN, and main mediators were showed in Table 2. The U.S. is always the most important mediator transmitting indirect competition in 2004, 2010 and 2016. Besides, we find that large wood-forest-product importers, like Japan, Germany, China, are also the main mediators. The reason is that there is various import source for these countries, and these countries compete with plenty of countries, which contribute to great possibility of transmitting countries' competition. Although top ten countries are almost the same,

Table 2
The main mediators over time.

Rank	2004	2010	2016
1	The U.S.	The U.S.	The U.S.
2	Japan	Japan	China
3	Germany	Germany	Germany
4	Croatia	China	Japan
5	Italy	Canada	UK
6	Canada	France	Ireland
7	UK	Ireland	Canada
8	China	Italy	Italy
9	France	UK	Spain
10	Spain	Australia	Belgium

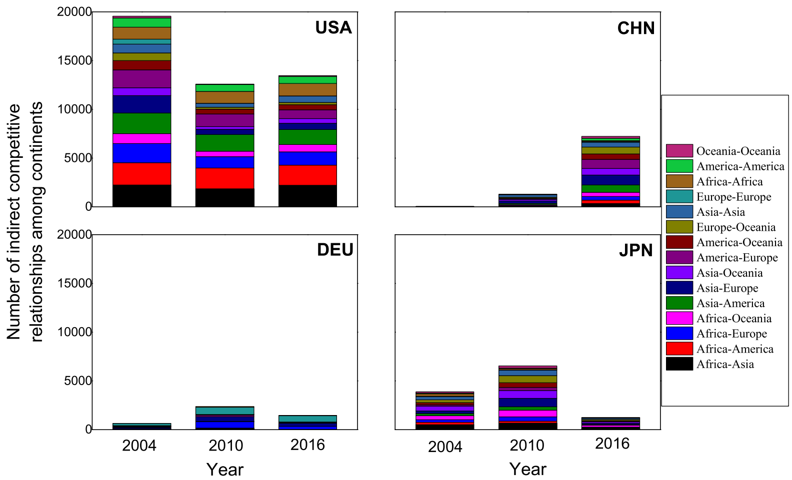

Fig. 6. The influence distribution caused by four main mediators.

the rank change over time. For example, China gradually plays an important role in transmitting the direct competition, while the rank of Japan gradually decreases, which is relate to their changes of import strategy.

Furthermore, the top four mediators (the U.S., China, Germany, and Japan) that influence the largest number of indirect competitive relationships are selected to explore the characteristics of the influence distributions. In Fig. 6, each stack bar and color indicate the sum and each number of indirect competitive relationship caused by specific country for one year, respectively. We can find that the U.S. affects the most indirect competitive relationships, but such impact firstly declines and then increases. The number of indirect relationships affected by China rapidly increases, indicating its increasingly significant position in the global competition pattern. Besides, because of differences in factors, such as geographical locations and import sources, the competitive regions affected by the four mediators are clearly different. The U.S., China and Japan have a global impact on competitive transmission due to their relatively diversified import sources, but Germany has only local influences. Meanwhile, each mediator has their main impact region. The U.S. mainly affects the indirect competition between Africa and America, China mainly affects the indirect competition between Asia and Europe, Germany mainly affects the indirect competition between European wood-forest-product importers, and Japan mainly affects the indirect competition between Africa and Asia.

4. Conclusion

Forest resources and forest product trade play important roles in promoting sustainable economic development and have attracted scholars' attention. However, the competitive relationships among forest-product traders and global spatial competitive evolution are still unclear. Thus, the paper selected global wood forest product trade data from 2004 to 2016, and studied spatial competitive evolution of global wood-forest-product-trading. The results show that there is widely competition in the global wood forest product trade among continents, and the tightness of competitive relationships gradually decrease over time. Secondly, core countries and periphery countries are clearly identified in the competitive network, and China, Japan, and the U.S., are the core countries influencing the evolution of core–periphery structure. Thirdly, the U.S. plays a significant role in the global competition system. But with the increment of demand for Asian market, China and other Asian countries gradually become the center of wood-forest-product-trading competition.

There is wide competition in global wood-forest-product trade, and the trading and competitive environment may become more complex in the future. Facing complex circumstance, each country should focus on corresponding strategy.

First, more participation. There are many agreements, like tariff agreement, in the global organizations, which are benefit for countries' import strategy. Participating in the organization will be good for their stable import. Second, more cooperation. Large importers play significant roles in global competition, but, as for buyers, they mostly lack bargaining power and may face uncertainty risks. More cooperation can help importers to avoid risk. Third, more adjustment. Forest-product importers should adjust their import strategy along with the change of market to maintain the diversification of supply, and relieve the pressure of wood-forest-product-trading competition.

However, there are still some limitations for our research. First, some important factors, like wildfire [28] and politics [29], affecting forest resources, and global wood product trade have not been explicitly considered. Considering these factors may uncover more evolutionary laws of competitive network. Second, some regional and global organizations (like EU, APEC, B&R and OECD) may affect global economy and society. Exploring the impact of these organizations on global wood-forest-product competitive relationships would reveal more spatial competitive characteristics of global wood forest product trade. Third, the paper mainly considered the competition from the perspective of importers, but there may be competitive relationships among exporters. Exploring the competition from the perspective of wood-forest-product export might reveal more interesting evolutionary laws of competition.

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